

On amplitude oscillation of vibrations of strongly anisotropic high-temperature superconductors of BiPbSrCaCuO system.

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Abstract

Effect of oscillations of the vibration amplitude of cylindrical sample suspended by a thin elastic thread and vibrating in a transverse magnetic field and containing 2D quasi-two-dimensional vortices (pancakes), was observed in the strongly anisotropic high- T_c superconductor of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ system.

Key words: Pinning, Vortex lattice

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At investigation of $3D - 2D$ transition in anisotropic high-temperature superconductors [1], we used the supersensitive mechanical method of investigation of dissipation processes [2]. Measuring the logarithmic decrement of damping δ as a function of outer magnetic field in the mixed state, a sharp decrease of dissipation was established which finished above the determined values of the field (of the order of 2000 Oe). This decrease is so great that the dissipation turns to be equal to that of background observed without magnetic field. This large change of dissipation, apparently, is connected with the increase of critical current, which should be observed at the transition of 3D three-dimensional vortices in quasi-two-dimensional 2D ones [3].

At a further increase of magnetic field the dissipation is not practically changed, in any case, at fields of the order of 2000 Oe and higher up to some definite field on the curve of magnetic field H dependence of δ the plateau is observed in some case, but at higher values of H the dissipation begins to decrease slightly and sometimes it turns out to be lower than its value without magnetic field (naturally, the sample temperature is $T < T_c$).

Let us present, for example, the $\delta = f(H)$ dependence at temperature $T = 93$ K (Fig.1). The critical temperature of our sample is $T_c = 107$ K.

As it is seen from the figure, the plateau of logarithmic decrement of damping is observed on $\delta = f(H)$ curve in the range of magnetic field from 2000 to 2800 Oe. At further increase of the magnetic field up to value $H \approx 5000$ Oe the energy dissipation continues to decrease gradually.

The particular attention should be paid to the range of dissipation plateau (2000 – 2800 Oe). In this range of magnetic fields the sharp change of energy dissipation dynamics takes place. On the other hand, in magnetic field range from $H = 0$ to $H = 2000$ Oe and from $H = 2800$ Oe and higher, up to maximum field $H \approx 5000$ Oe measured by us, the character of dissipation is standard: the vibration amplitude decreases gradually by exponential law (see Fig.2) and from these data δ is defined. In contrast to this picture in the range of fields from $H = 2000$ Oe to $H = 2800$ Oe the time dependence of vibration amplitude is sharply changed and pronounced oscillations with the period of $20 \div 70$ sec. occur disappearing just as soon as the magnetic field value leaves the plateau region. In the given case at temperature $T = 93$ K the oscillations disappear and $\delta = f(H)$ dependence turns out to be as smooth as at fields $H < 2000$ Oe.

On $\delta = f(H)$ curve plateau is not always observed at fields more than $H > 2000$ Oe at higher temperatures but there is a gradual decrease of vibration damping. As an example of such behavior let us take $\delta = f(H)$ dependence for temperature $T = 100$ K (Fig.3). Here, also as at $T = 93$ K, when the magnetic field becomes > 2000 Oe, in particular, when fields $H > 3000$ Oe, the vibration amplitude oscillations appear (Fig.4), disappearing at $H = 5300$ Oe. It should be noted that the frequency of suspension system also oscillates with the amplitude and one should especially emphasize that maximum of vibration amplitude coincides with the frequency maximum, and the minimum of vibration amplitude with the minimum of frequency. One of possible explanations of this phenomenon, in particular, the oscillation of frequency and amplitude, is that in the crystal lattice of investigated sample there are directions along which vortices could be fixed more effectively than along other directions.

As it has been already noted, in 2000 – 2800 Oe interval the time dependence of amplitude is not exponential and as a result, the usual measurement of dissipation decrement becomes impossible. The values for this range shown in Fig. 1 and Fig. 3 are determined by envelops of curves, shown in Fig.4a and Fig.4b.

After the appearance of the oscillations of vibration amplitude their frequency first decreases with the increase of magnetic field, and the amplitude increases. The amplitude increase and frequency decrease process continues up to the definite field and further, on the contrary, the amplitude decreases with the increase of field, and the frequency of oscillations decreases and, finally, at

$H = 5300$ Oe oscillations disappear. At fields $H > 5300$ Oe the dependence of amplitude on time turns to be as smooth as at fields $H < 2000$ Oe, shown in fig.2.

It turns out that the similar behavior of the frequency of oscillations can be observed at a fixed field. With the decrease of the amplitude of vibrations at $T = 100$ K and $H = 4200$ Oe, as it is seen from the plot presented on Fig.4(a), the frequency of amplitude oscillations first decreases, reaches the minimum and then it begins to increase, with the decrease of amplitude, down to the full disappearance of oscillations.

The investigation of temperature and field dependence of the beginning and ending of oscillations gave us the possibility to reveal the region on $H(T)$ diagram where the oscillations of vibration amplitude are observed - Fig.5 (dashed region). As it is seen from the figure, with the decrease of temperature this region of field is narrowed and it is possible that at low temperatures it can even disappear.

In the previous work [1] the onset of plateau we related to the final decay of three-dimensional $3D$ Abrikosov vortices and appearance of quasi-two-dimensional $2D$ vortices (pancakes). At the same time we proceeded from the considerations given in work [3], where with the help of computer calculation it was shown that at the decay of $3D$ vortices into quasi-two-dimensional $2D$ ones, the critical current should increase drastically. This means that the dissipation is decreased as it was observed by us.

Note that the estimation of the field value at which $2D$ quasi-two-dimensional vortices (pancakes) begin to appear gives namely field $H \approx 2000$ Oe [1,4].

One more argument in favor for the $3D - 2D$ transition at field $H \approx 2000$ Oe is related to the fact that the amplitude effects are strongly suppressed at fields higher than the transition to quasi-two-dimensional state (at fields ≥ 2000 Oe). Both the suspension system vibration frequency, and the damping in these fields and in higher ones depend more weakly on amplitude (Fig.6), than at weak fields when the vortices are three-dimensional $3D$ ones. However, as for the amplitude dependence of damping and vibration frequency for the regions where amplitude oscillations are observed, if they are plotted to the same scale for the magnetic field region with $2D$ vortices ($H > 2000$ Oe) (Fig.6) and weak magnetic fields where $3D$ three-dimensional vortices are observed ($H \ll 2000$ Oe) (Fig.7), it is seen that in the case of quasi-two-dimensional $2D$ vortices in the amplitude oscillation region amplitude effects are weaker than in the case of $3D$ vortices. However, under these conditions the amplitude effects are smaller as compared with the great amplitude effects observed in classical superconductors of the second kind for three-dimensional $3D$ Abrikosov vortices [2,5].

In the case of field $H = 110$ Oe (Fig.7), vortices are clearly three-dimensional Abrikosov ones, though in these layered samples of high-temperature BiPbSr-CaCuO superconductor these amplitude effects are not so strong as in classical superconductors of the second type, but, they clearly denote the significant amplitude dependence of both δ and ω . As it is seen from the presented plot, here the amplitude effects are higher than their values in fields being close to and higher than $3D - 2D$ transition fields. For classical superconductors of II type, where the amplitude effects are considerably larger, the data were presented in works [2,5]. The amplitude effects caused by the motion of Abrikosov vortices in the vibration experiments with superconductors of II type were observed by us for the first time [6,7] and explained by V. Galaiko [8] who connected these effects with concentrations of pinned and free vortices. According to his theory the concentrations of free and pinned vortices change with the change of magnetic field and their interaction is the reason of damping and, consequently, the vibration damping in the mixed state changes with the change of magnetic field. The similar amplitude effects for δ and ω were observed in high-temperature superconductors as well [9,10].

The significant decrease of amplitude effects in the layered high-temperature superconductors at fields $H > 2000$ Oe points to the fact that in our experiments the vibration amplitudes are not sufficient for tearing of vortices from pinning-centers and therefore, apparently, practically all vortices are pinned, and the concentration of free vortices is almost equal to zero $n_{fr} \approx 0$ and the concentration of fixed vortices is almost equal to unit $n_{pin} \approx 1$, resulting to the significant decrease of dissipation energy. However, it should be noted that, apparently, a small concentration of free vortices remains different from zero $n_{fr} \neq 0$ causing the oscillation effects of vibration amplitude, and also the dissipation processes at fields $H > 2000$ Oe being too small, but still different from zero.

The very fact of the existence of vibration amplitude oscillation is the most unclear problem. It is not clear where the energy for vibration amplitude enhancement comes from and why its appearing-disappearing has a periodical character.

Possible doubt that this effect, probably, is not connected with the processes taking place in the investigated superconductors, but it is caused by superposition of different vibrations on axial-and-torsional vibrations of the cylindrical sample (the description of the device installation is given in [1]) is verified by the following facts:

- 1). The frequency of intrinsic axial vibration of the system ($\omega_0 = 1,2560$ sec $^{-1}$) is not in simple relation with the frequency of radial vibrations $\omega_r = 9,96825$ sec $^{-1}$; 2) Using the other sample with considerably smaller number of vortices, the mechanical vibration frequencies at zero field remained unchanged,

but frequency of axial vibrations at magnetic field in the range of vibration amplitude oscillation was noticeably changed (from $\omega \approx 3,2 \div 4,3 \text{ sec}^{-1}$ to $\omega \approx 2 \text{ sec}^{-1}$).

The testing experiment eliminated also the possibility of the influence of mechanical noise in vibrating system, its inertia moment (by replacement of discus) and of the change of torque (by replacement of elastic thread by two - upper and lower threads [11], intrinsic frequency ($\omega_0 = 1,047 \text{ sec}^{-1}$) and frequencies at the presence of field $\omega = 1,5 \div 1,75 \text{ sec}^{-1}$ were essentially changed, but the magnetic field interval, where the oscillation of vibrations is observed, remained unchanged).

In the testing experiment of the other type the inertia moment was continuously changed almost four times in the process of experiment. These experiments will be described in more detail in the next paper.

These experiments showed that in spite of the change of intrinsic frequency of vibration system, the vibration amplitude oscillations are observed at the same magnetic field interval, as in the above described experiment.

Thus, we made sure that the phenomena of vibration amplitude oscillations are directly connected with processes taking place in superconductors being in magnetic field, rather than with side effects.

Let us try to explain situation at least in general terms.

As it is known [12,13] in the tilted field when there are weak Josephson links between the layers, the quasi-two-dimensional 2D system of vortices is created, interconnected by Josephson junctions (Josephson links) that is realized only in the case when the angle of inclination of internal field $\theta_h > \theta_0 = \arctg\Gamma$, where Γ is the anisotropy factor $\Gamma = M/m$, M is the effective mass along c axis, and m is the effective mass in the basis (a, b) plane. In our case $\Gamma = 3000$ and the estimation gives $\theta_0 \approx 89, 98^\circ$.

The angles of rotation in our experiment not exceed $\varphi \approx 1,0 \text{ rad}$. Consequently, in our experiments the Josephson vortices do not appear the creation and disintegration of which could, principally, cause the phenomenon of vibration amplitude oscillation. Oscillations can not be also explained either by R. A. Klemm's model [14]. The mechanical moment oscillations predicted by him should be observed at large angles $\theta > \theta_{cr} = 89, 64^\circ$, being more than the maximal values of vibration amplitude in our experiments $\varphi_{max} \approx 1,0 \text{ rad}$.

One of the possible mechanisms of phenomenon observed by us can be connected with the following: during vibration of our sample 2D vortices together with the sample are turned relative to the magnetic field and, as a result, the flux of magnetic field in pancakes planes parallel to the basic plane of the

crystal (**a,b**) is changed. Thus, the alternative electromotive force of induction arise causing the creation of alternative field superimposed on the basic steady magnetic field H . The interaction of magnetic field with the sample takes place.

The phase shift between forcing vibrations (axial vibrations) being possible in this case and forced vibrations (pancake vibrations) can be the cause of amplitude oscillation, as it increases at the coincidence and closeness of phases but with the divergence of phases the amplitude increase is changed by its decrease.

So far we have not been able to give the more detailed description of this process which, apparently, should be connected with the vortex slipping (vortices are more strongly pinned in the direction perpendicular to the direction of their vibrations than in the direction of vibrations).

One should also discuss the possibility of generation of vortices of the different waves and their possible influence on the character of the sample vibrations in the system investigated by us.

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Figure Captions

Fig.1. Logarithmic decrement of damping δ dependence on the strength of outer magnetic field H . Temperature $T = 93$ K.

Fig.2. Vibration amplitude decrease of the suspension system on time. $T = 93$ K, $H = 80$ Oe.

Fig.3. Logarithmic decrement of damping δ dependence on the strength of outer magnetic field H . Temperature $T = 100$ K.

Fig.4. Vibration amplitude and frequency dependence of the suspension system on time. $T = 100$ K, **a** – $H = 4200$ Oe, **b** – $H = 4550$ Oe.

Fig.5. $H(T)$ phase diagram. Here in the dashed part of diagram oscillations of vibration amplitude of the suspension system are observed.

Fig.6. Damping δ and vibration frequency ω dependence on amplitude. $T = 100$ K, $H = 3500$ Oe.

Fig.7. Damping δ and vibration frequency ω dependence on amplitude. $T = 100$ K, $H = 110$ Oe.

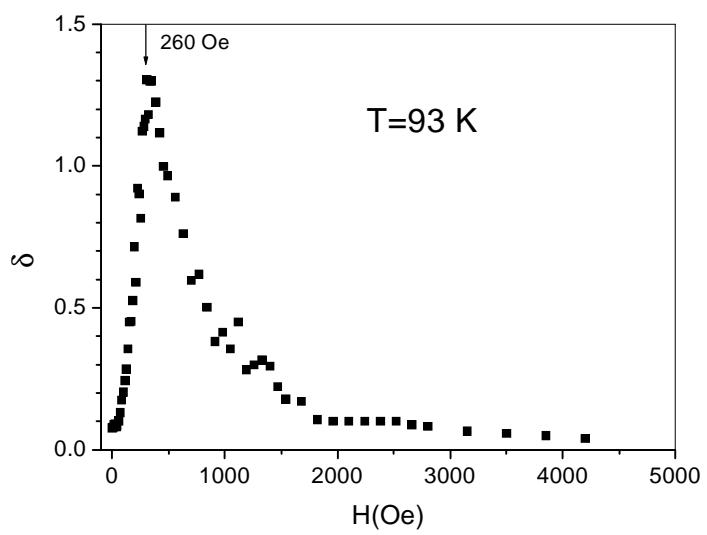


Fig.1

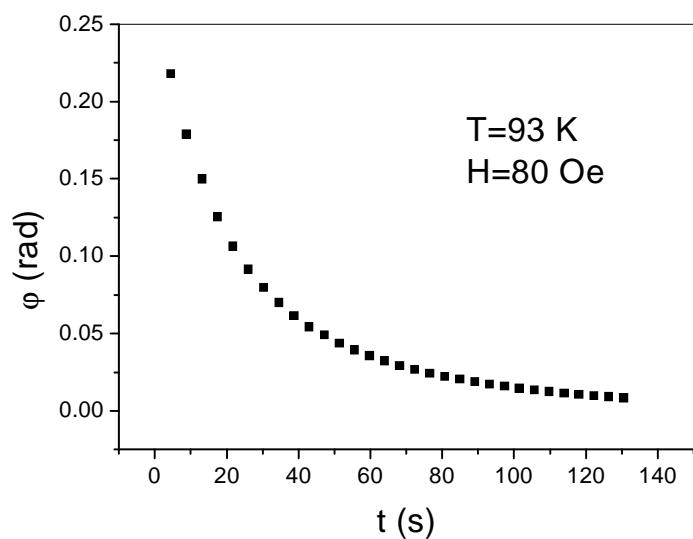


Fig.2

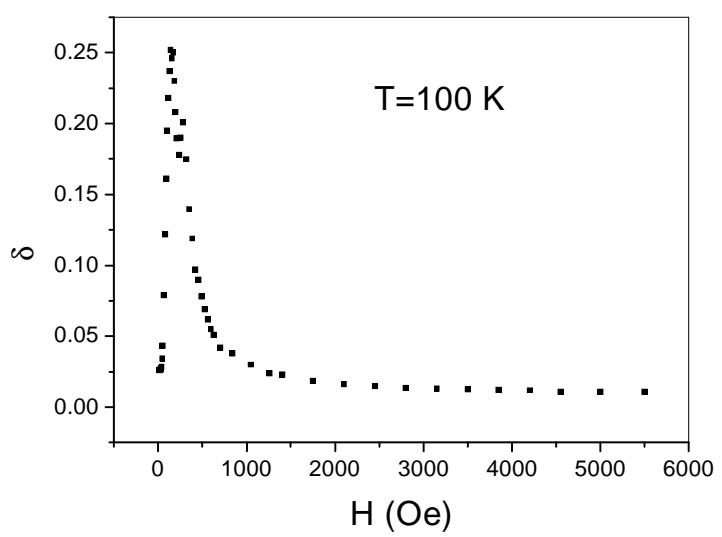


Fig.3

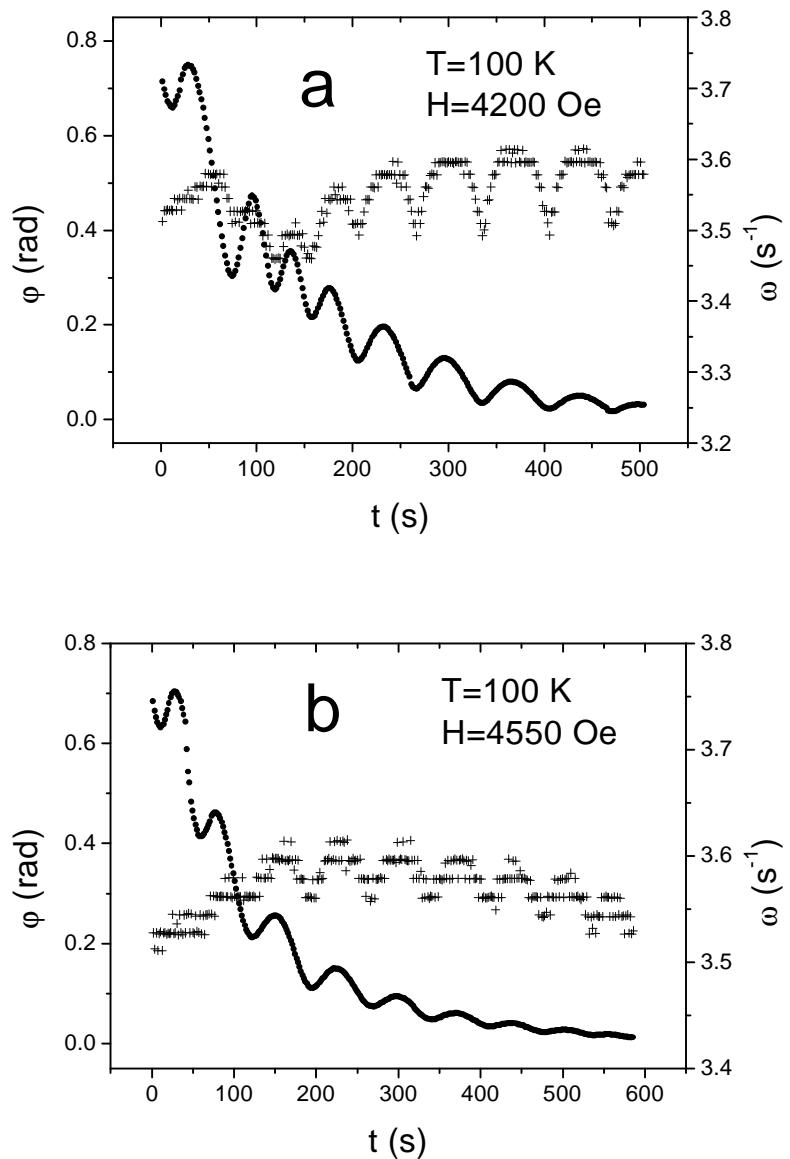


Fig.4

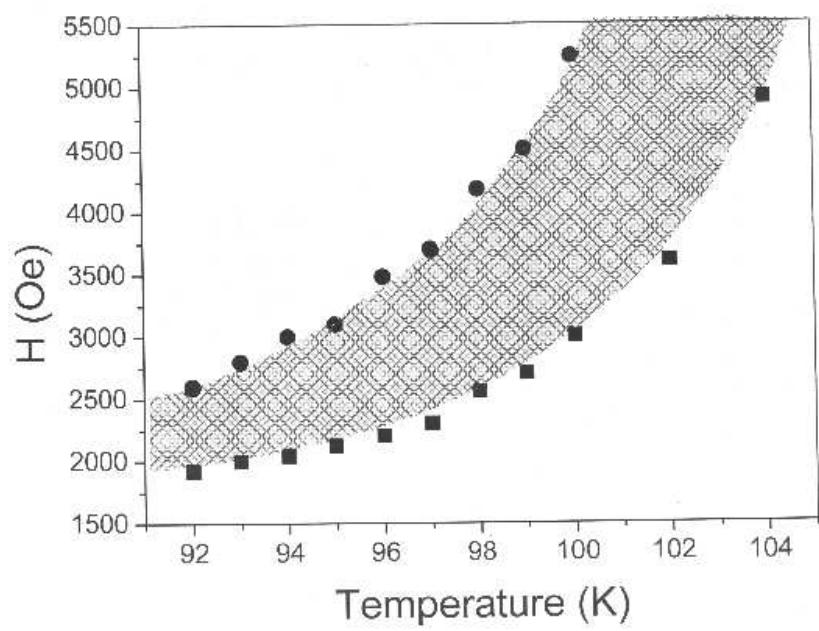


Fig.5

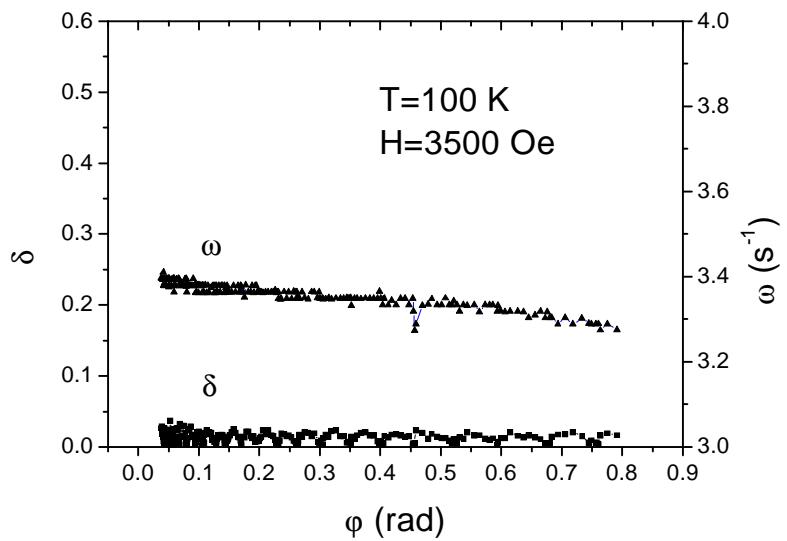


Fig.6

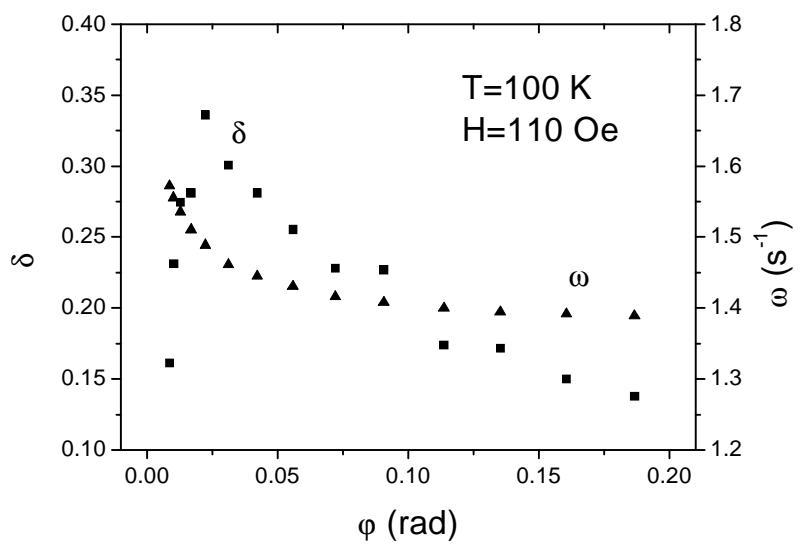


Fig.7